A Survey of Eye Tracking in Automobile and Aviation Studies: Implications for Eye-Tracking Studies in Marine Operations

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***Abstract*—In the last decade researchers have increasingly considered eye tracking of the operators of cars and airplanes as a means to address human error and evaluate operational effectiveness. This article presents a systematic survey of recently published papers about this approach in service to the question as to whether eye tracking can be used to address operational safety in marine operations. The surveyed papers are selected systematically and were categorized according to several defined characteristics. Eye tracking depends on defining operators' areas of interest (AOIs) and measuring operators focus on them over time. We identified the method of defining AOIs as a key distinction between studies; the papers fell into four categories, depending on whether researchers relied on an expert, based it on the stimulus itself, or used an attention map or a clustering algorithm to define the AOIs they used. The article also summarizes and analyzes the design and procedure of the eye-tracking experiments in the papers. Based on the features of marine operation, instruction on AOI definition in different scenarios is extracted; guidelines on experimental design and procedure selection are provided. In the article's conclusion we apply the results to a case study of a heavy-lifting operation to demonstrate the effectiveness of eye-tracking in marine operations.**

***Index Terms*—Area of interest (AOI) definition method, automobile and aviation, eye tracking, knowledge transfer, marine operation.**

I. Introduction

EYE tracking is a sensor technology that captures human eye behavior. It has been widely used to gain insight about automobile operation [1], [2], aviation [3], [4], web searching [5], reading [6], drawing [7], medical surgery [8], energy [9], mining [10], offshore [11], and the effect of depictions of healthy and unhealthy foods on children [12]. Among these, automobile and aviation are the two frequently studied fields with a wide range of research applications. Studies in these areas have focused either directly on safety or mental testing of drivers/pilots. Those focused on safety measure hazard detection [13], steering [14], automated driving [15], luminance [16] by drivers; and landing [17], conflict detection [18], air traffic control [19] by pilots. Mental tests address mental workload [20], [21], and fatigue [22], [23].

Results of eye-tracking studies show that human error causes most accidents. With respect to automobiles, this reflects the fact that driving virtually always consists of a series of complex behaviors, such that deviation from intention, other drivers' expectations, or desirability [24] may cause severe injury and even death. Similarly, human error in aviation is also critical; it can lead to catastrophic consequences that passengers have a slim chance of surviving. In addition to eye tracking, researchers have studied human error by means of electroencephalography and electrocardiography. Among these, eye tracking is considered one of the most effective if correctly recorded, because human eyes are responsible for obtaining 70% of information humans take in. When paired with rational analysis and visualization methods, eye tracking can support significant engineering improvement.

Human error also affects marine operations. The growth of demanding marine operations, such as offshore petroleum extraction, subsea pipeline deployment, and wind turbine installation, has increased the threat human error poses to the safety of people and property [25]. Attempts have been made to use eye tracking to assess marine operations [25]–[28], but systematic instructions for using the method and conducting experiments and assessing its effectiveness remain sparse.

There are similarities between automobile, aviation, and marine operation in terms of research topic, experimental design, and procedure in simulator. This suggests eye-tracking methods for marine operation can be developed based on evidence of the approach's utility in automobile and aviation operation. Fig. 1 shows the concept scheme of our work. Methodology and experiment are the two concerns for knowledge transfer. More specifically, efforts have been made to identify regions of visual stimuli, that is, areas of interest (AOI) that draw the human eye [29]. Likewise, analysis is conducted according to methodology from experimental design to experimental procedure development. Table I lists the terminologies frequently used in implementations of eye tracking.

The objective of this work is to evaluate the eye-tracking applications in automobile and aviation in order to transfer

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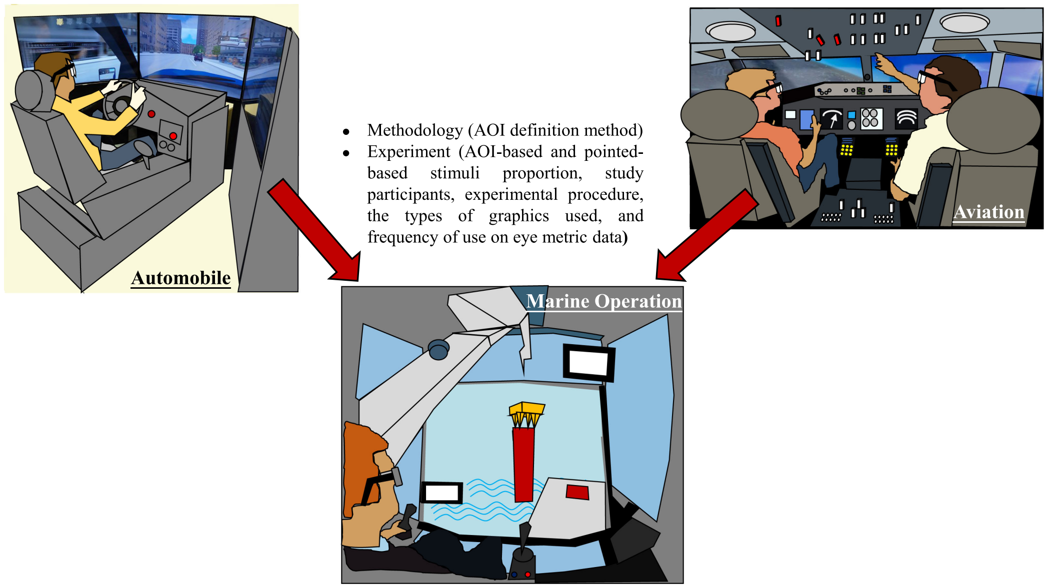

Fig. 1. Transferring eye-tracking methodologies and experiments to marine operation from automobile and aviation research.

TABLE I
TERMINOLOGY IN EYE TRACKING

Terminology	Description
Stimulus	The visual content that is shown to participants during the experiment using eye tracking [29].
Gaze	The most basic data tracking eye movement, measured by real-time spatial location reflecting from the eyes as they land on the stimulus. It is measurable and can be understood as the output of the eye tracking hardware.
Fixation	The aggregation of the gaze points based on a temporal or a spatial way [30]. It denotes a period when human eyes are locked on the specific region or object. It is the feature eye-tracking related studies analyze the most often.
Saccade	The eye movement from one fixed point to another. The average duration of a saccade has been measured at 30-80 milliseconds [30].
Glance	A subconscious eye movement activity with duration of a maximum of 100 milliseconds [31].
Dwell time	The total time of exploration in an AOI [32].
Pupil	The most frequent used pupil-related metrics are the pupil changes in dilation and diameter. The relative changes in pupil diameters are reported that has correlation with the mental workload [31].
Blink	Many recent studies have used blink as a metric to study eye-tracking, and evidence shows that blink correlates with mental workload [31].
Scanpath	An eye movement sequence that consists of fixations and saccades [33]. It can also depict the spatial and temporal information simultaneously.

knowledge from these applications to marine operations as a way to better comprehend human error. The rest of this article is organized as follows. Section II provides the literature search approach and the categorization scheme used. Section III introduces the state of the art of the current AOI definition methods. In Section IV, the experimental design and procedure of eye tracking in automobile and aviation are analyzed and discussed. Section V offers guidelines on the selection of the AOI definition method, as well as experimental design and procedure in marine operation. Section VI concludes the article.

II. METHODOLOGY

A. Literature Search Approach

This work is structured and guided by the PRISMA statement provided by Moher *et al.* [34]. Fig. 2 shows the process of the paper selection following the PRISMA flow diagram. The format and design were revised based on Monteiro *et al.* [35]. Papers reviewed here were published between 2010 and 2020, all have the keyword listed in the figure in the title or abstract. Further exclusions eliminated papers that did not provide the full experiment and qualitative analysis.

B. Paper Categorization

A taxonomy describing the characteristics of the surveyed papers is presented to highlight and categorize the surveyed papers based on several characteristics. Fig. 3 shows the summarized categorization of the surveyed papers separated according to the defined characteristics. The columns depict the number of papers in the separated groups. At the same time, Table II shows the papers selected from the surveyed papers categorized by the defined characteristics. These defined characteristics are AOI-based stimuli and point-based stimuli; static and dynamic stimuli; temporal, spatial, and spatio-temporal visualizations; simulated scenario or real scenario; expert-novice and nonexpert-novice. The categorization approach is inspired by

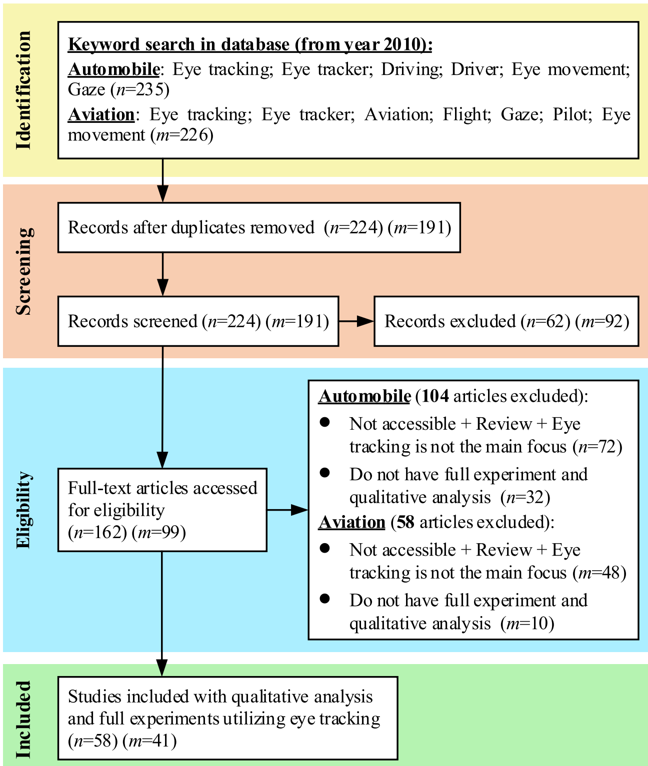

Fig. 2. PRISMA flow diagram.

TABLE II
PAPERS SELECTED FROM THE SURVEYED PAPERS CATEGORIZED BY THE DEFINED CHARACTERISTICS

		Typical paper	
	Characteristics	Automobile	Aviation
AOI-based stimuli	Static stimuli	[13] [38] [37]	[21] [39] [40]
	Dynamic stimuli	[20] [41] [42] [43] [44]	[3] [45] [46] [47] [48]
	Temporal	[15] [49]	[23] [50]
	Spatial	[51] [52] [53] [54] [55]	[56] [57] [58] [59] [60]
	Spatio-temporal	[20] [61] [62] [63] [64]	[3] [18] [40] [47] [48]
	Simulated scenario	[15] [49] [61] [65] [66]	[39] [67] [68] [69] [70]
	Real scenario	[41] [42] [71] [72] [73]	
	Expert-novice	[13] [54] [74] [63] [75]	[76] [77] [78] [40]
	Non-expert-novice	[15] [61] [62] [79] [80]	[50] [56] [81] [82] [83]
Point-based stimuli	Static stimuli	[84]	[19] [85] [86]
	Dynamic stimuli	[14] [87] [88] [89] [90]	[17] [85] [91] [92] [93]
	Temporal	[90] [94] [95] [96] [97]	[85] [86]
	Spatial	[88] [98] [99] [100] [101]	[17] [102] [19] [103] [91]
	Spatio-temporal	[1] [104] [105] [106]	[93]
	Simulated scenario	[84] [88] [89] [104] [107]	[91] [92] [93] [85] [17]
	Real scenario	[14] [16] [90] [98]	
	Expert-novice	[101] [22]	[92] [93]
	Non-expert-novice	[1] [90] [104] [105] [107]	[19] [86] [91] [92] [103]

Blascheck *et al.* [29] and Andrienko *et al.* [36] and revised based on the characteristics of driving and aviation.

1) AOI-Based Stimuli and Point-Based Stimuli: Several papers focus on these types of stimuli. Andrienko *et al.* [36] termed such papers "AOI focused" and "movement focused," while Blascheck *et al.* [29] called them "AOI based" and "point based." Papers that examine eye movements in relation to AOI-based stimuli focus on the transition and relation of AOIs the researchers define [29]. Papers that examine point-based stimuli use eye movement as the primary. In both cases the focus is on transitions between the spatial or temporal order of the eye-tracking data [36].

2) Static and Dynamic Stimuli: Static stimuli include static visualizations and pictures [37]; they do not change [29]. Dynamic stimuli are changeable, such as videos projected in the simulator or, in real-world scenarios, the view out the window and in the head-up display.

3) Temporal, Spatial, and Spatio-Temporal Visualizations: Blascheck *et al.* define graphical representations of data visualizations as temporal, spatial, or spatio-temporal [29]. Temporal visualizations are often time-series plots meaning time is the parameter on one axis. Spatial visualizations focus on coordinates of the gaze or fixation in space. Spatio-temporal visualizations show both temporal and spatial aspects of the data [29].

4) Stimulated Scenario and Real Scenario: The research theme, objective, cost, and other conditions will dictate whether measures are conducted in a simulated scenario, a real scenario, or both. Simulated experiments typically occur in a driving or flight simulator, which have been well developed in recent years.

5) Expert-Novice and Nonexpert-Novice: Automobile-related and aviation-related studies that use eye tracking can either compare experts and novices or use only experienced participants to study the influence of experience and expertise on eye movements. Such studies can be used to improve training programs for novices.

III. AOI DEFINITION METHOD IN EYE TRACKING OF DRIVERS AND PILOTS

AOI refers to specific regions that have crucial meaning in specific studies or tasks [108]. A total of 37 automobile-related papers are AOI-based and 32 aviation-related papers are AOI-based. The AOI selected for a study has enormous impact on its findings. Studies reflect four approaches to defining the AOIs. These methods can be described according to whether the AOIs are defined by experts, generated by stimulus, or defined by an attention map or a clustering algorithm.

A. Expert Defined AOIs

The use of experts' opinions to define the AOI, the eye tracking will measure, is based on the understanding that experts have significant knowledge of what operators should be looking at. Expert-defined AOIs can be used in various stimuli [30]. For example, Sarter *et al.* [109] and Dehais *et al.* [18], [110] examined automation monitoring strategies and performance of pilots through expert-defined AOIs. Koh *et al.* [111] studied the eye behavior of scrub nurses during surgery through expert-defined AOIs. A total of 25 of the surveyed papers (25.2%) use an expert's definition to determine their AOI, of which 10 were related to automobile operation and 15 to aviation operation.

Conditions: The expert-defined method is frequently applied in scenarios with the following three experimental conditions. The first is that high fixation density areas cannot be predicted before eye-movement data are acquired. For example, when participants are asked to drive in rural areas [44] or city roads [64] for a long time, it is difficult to predict the high fixation density area in advance. The second is that there are similar studies to refer to for appropriate and quick AOI definition. The third is that there is no clear way to separate the stimuli. In some studies,

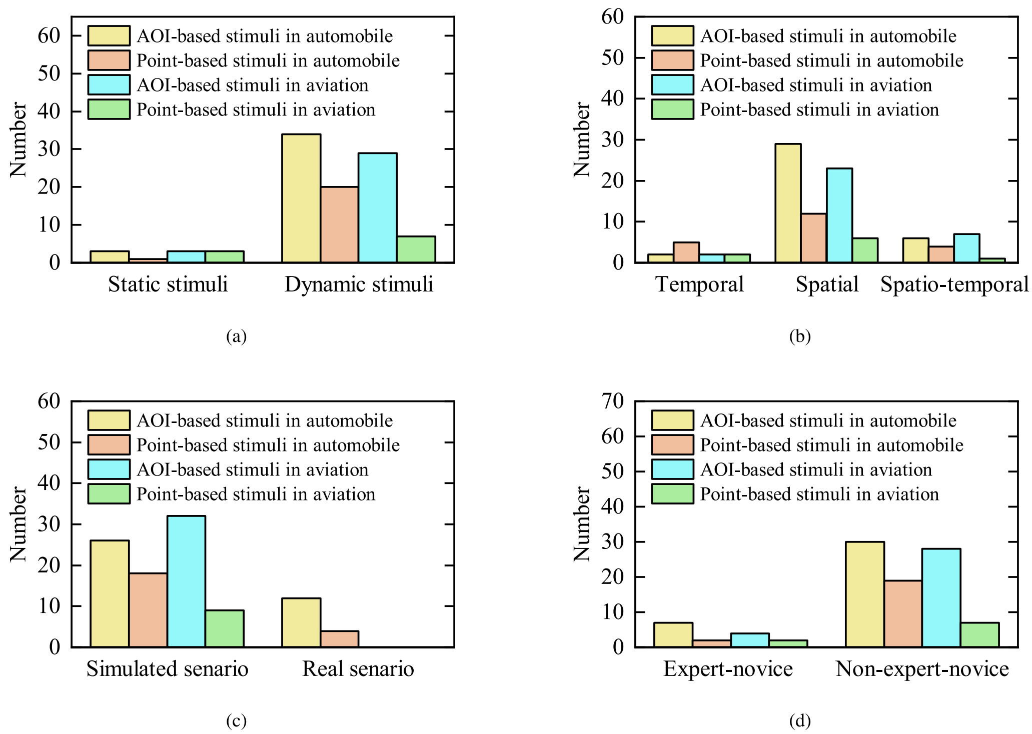

Fig. 3. Summarized categorization of the surveyed papers separated with the defined characteristics. (a) Static and dynamic stimuli. (b) Temporal, spatial, and spatio-temporal visualizations. (c) Simulated scenario and real scenario. (d) Expert-novice and nonexpert-novice according to AOI-based stimuli and point-based stimuli.

the stimuli contain too much visual information for AOIs to be defined and separated easily.

Processing: There are several ways to define AOIs by experts' opinions. One way is to simply ask experts to define the AOIs. Another is to ask them many questions about operations that will lead to identification of the AOI. Finally, studies may use AOIs experts have defined for previous similar studies. This generally requires that the research questions be extremely similar. Reynal *et al.* [82] and Dill *et al.* [83] used the AOIs defined in previous works of Dehais *et al.* [18], and Dill and Young [47], respectively, to study flight safety and mental workload of pilots. Some studies use combinations of these three approaches. Fig. 4(a) shows the AOIs studies that use expert-defined method rely on in automobile experiments: The dashboard, the road ahead, side views, and the rest of the view out the windshield.

Validation: The selected AOIs should be validated. This is usually done by comparing the selected AOIs with the recorded eye-movement data. If the defined AOIs overlaps with the high fixation density area projected by the expert participants, their definition is verified. In addition, feedback from experts is also a good reference for validating the AOI definition.

B. Stimulus-Generated AOIs

The stimulus itself can be utilized to create AOIs [30]. Usually, the AOIs are defined by separating the stimuli into several parts according to defined visual boundaries and color, either manually or by computer analysis. This approach has the advantage that the AOIs can be simply defined and generated in some situations. This may be why it is the most common method in the surveyed papers, appearing in 23 of the 37 AOI-based automobile-related papers and 17 of the 32 aviation-related papers.

Condition: Two conditions prompt researchers to generate AOIs using stimuli. This first is that the research question concerns a particular area of fixation. For example, fixations on specific road signs [38] or hazard indicators can be an important criterion for determining whether a driver will be aware of a hazard the sign references; fixations on specific panels are therefore an essential standard to evaluate the performance of pilots [3], [48]. Another necessary condition of the stimuli-generated method is that stimuli are easy to separate. For example, studies of drivers have focused on the speedometer, the rear-view mirror [112], billboards, the road ahead [54], and pedestrians [63].

Processing: Stimulus-generated AOIs can be applied to eye-tracking studies in several ways. When the research theme and stimuli are decided, the AOIs can be selected by the size and shape of the stimuli [23], [68]. Sometimes for convenience, the size of AOIs can be simplified into a rectangle [113]. Second, the whole stimuli can be separated into several AOIs [20]. In addition, there are dynamic AOIs defined by stimuli that changes as time goes [20], [63]. Fig. 4(b) shows the typical AOI setting for studies that use the stimulus-generated method. The AOIs are defined as the dashboard and out the window.

C. Attention-Map Defined AOIs

An attention map, also called a fixation map or a heat map, can also be an alternative way to define AOIs. Creating an attention map involves two main steps: Cutting off the peak of the Gaussian landscape model and taking the selected area as the defined AOIs. Van der Laan *et al.* [114] used this method to

Fig. 4. Typical AOI setting definitions determined by (a) experts (adapted from [32]), (b) generation from stimulus (adapted from [68]), (c) attention map (adapted from [40]), and (d) clustering algorithm (adapted from [75]).

define AOIs by manually deciding the height when they cut the peak of their attention map.

Conditions: The attention map can be used for any study, but its main advantages emerge when other approaches are not available, such as when the stimulus of interest has no clear separation boundaries. When no similar research that might guide the selection of stimuli exists, attention maps offer a potential solution.

Data Preprocessing: For studies that use the attention map defined method, experimental data are usually preprocessed by correcting the eye-movement data. Such data can be mistakenly recorded, and hence manual correction is needed. The manual correction is usually undertaken by checking and correcting the recorded coordinates of the eye-movement data based on the experimental data frame by frame. Then initial data is divided into multiple datasets.

Processing: In this method, first the attention maps of the participants are plotted based on the obtained data, and then these maps are overlapped into a new attention map. Through comparisons of all study participants' maps, the density boundaries emerge and determine the shape, margin, and size of the AOIs. Winter *et al.* [72], Locken *et al.* [62], and Dolega *et al.* [40] used attention maps to define AOIs in order to study the eye behavior of the drivers or pilots. Fig. 4(c) shows the typical AOI setting using an attention map defined method. Attention maps are built through the experiment instead of being used as a condition of the experiment. The AOIs are defined based on the obtained attention map. They are indicated with different colors to show their priority sequence according to the eye-movement density.

D. AOIs Defined by Clustering Algorithm

As with the attention map method, clustering algorithms define AOI after eye-movement data are collected. Clustering algorithms are used to assign gazes or fixations into subsets in a systematic and logical way. In most circumstances, scholars divide the gazes or the fixations by spatial coordinates [30].

The K-means clustering method is one of the most frequently used methods. This involves clustering n data points into k clusters based on counting the point to the spatially closest cluster and revising the centroid of the points [108]. Another type of clustering methods, such as the mean-shift algorithm [115], is based on density of data points. The core of the algorithm is to iteratively shift points to a higher density area, then cluster into AOIs. Gu *et al.* [116] used a mean shift algorithm to group fixation points into clusters. Other clustering algorithms exist. For example, Goldberg and Schryver [117] presented an algorithm to find fixation-like spatial clusters, the minimal spanning tree.

Conditions: Clustering algorithms are most often used to define AOIs under circumstances similar to those in which attention maps are used (the conditions described in Section III-C), but the clustering method is usually used when the AOI definition emphasizes clustering.

Data Preprocessing: The data preprocessing method described in Section III-C applies to the clustering defined method as well as in cases when attention maps are used.

Initialization: Defining AOIs by clustering algorithms frequently requires initialization of the parameters. Different algorithms require initialization of different parameters.

For example, in a typical K-means clustering algorithm method, the initial parameters are usually central coordinates for datasets. Hyperparameters, such as the cluster number k and the maximum iteration number n, can also be initialized; Xu *et al.* [75] initialized the successive iterations for a given cluster center and derivation parameter P in his research using the improved affinity propagation algorithm. These numbers can largely influence the clustering result and the performance of the clustering.

Iterations: Iteration is an important part of the clustering algorithm method. A machine must optimize the clustering result step by step based on the selected clustering method and the hyperparameters such as the cluster number k, and the maximum iteration number n, etc.

Validation: The clustering result needs to be validated because it is not always satisfactory, e.g., not consistent with research expectation. If the clustering results do not align with the requirements that the defined AOI number and AOI distribution show consistency with driving common sense [75], the solution usually is to change the initial value or some other parameters, and repeat the clustering procedure until satisfactory results are achieved [75]. Fig. 4(d) shows the typical AOI setting using a clustering algorithm method. The AOIs are defined based on the clusters obtained from the selected algorithms.

TABLE III
PARTICIPANT-RELATED PARAMETERS FOR THE SURVEYED PAPERS

Parameters	Automobile	Aviation
Mean participant number	26.81±18.88	25.91±26.87
Mean participant age (years old)	32.35±12.95	32.54±6.44
Driving years (y) / Flying hours (h)	14.03±11.51	5070.92±5975.92

IV. EXPERIMENTAL DESIGN AND PROCEDURE OF EYE TRACKING IN AUTOMOBILE AND AVIATION

This section will analyze and compare the experimental design and procedure used in the surveyed papers. The subjects addressed will include the proportion of papers that are based on AOI stimuli or points stimuli, study participants, experimental procedure, the types of graphics used, and frequency of use on eye metric data.

A. AOI-Based and Pointed-Based Stimuli Proportion

Fig. 5 denotes the proportion of surveyed papers about automobile operation and aviation that are, respectively, based on AOI stimuli and point stimuli. Clearly more papers are based on AOI stimuli. The likely explanation is that driving and flying both call for great focus on changes in AOIs and the relationship between them.

B. Study Participants

Table III shows the participant-related parameters for the surveyed papers: The mean number of participants, their mean age, and their mean number of driving years or flying hours. Years are listed in one case and hours in the other because most of the surveyed papers for each type of vehicle operation used these units.

All of the automobile-related papers recorded the mean participant number (MPN), and 35 of 41 aviation-related samples did. Across these papers, the MPN for both industries is very close, 26.81 and 25.91, respectively, and both have a large standard deviation. The greater MPN for the automobile papers is unsurprising, given the relative prevalence of driver's licenses and pilot's licenses.

Fewer of the surveyed papers reported mean participant age (MPA): 49 out of 58 automobile-related papers, and only 23 of 41 aviation papers. However, the average age, where there was report, was almost identical for each group, between 32 and 33. Perhaps, given the relative prevalence of driving and flying and the greater number of hours of practice it takes to learn to pilot a plane effectively, it is unsurprising that the standard deviation in automobile-related studies is twice as wide as that of aviation-related studies. Researchers studying driving can much more readily select a bounded age group.

Driving years and fly hours, of course, are not readily comparable. These also were recorded in a minority of both kinds of papers: 24 of the 58 automobile-related papers and 15 of the 41 aviation-related papers.

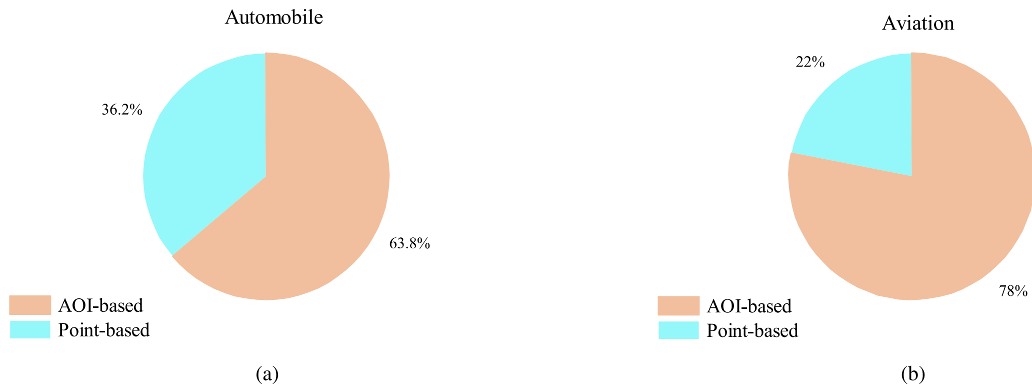

Fig. 5. Proportion of surveyed papers on (a) automobile operation and (b) aviation operation that are based on AOI stimuli and point stimuli.

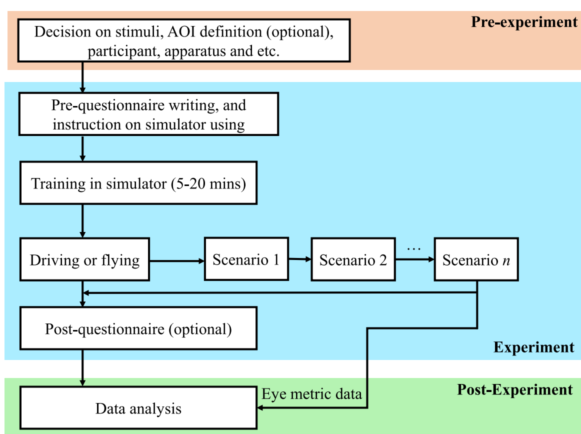

Fig. 6. Stages of the experimental procedure in the surveyed papers.

C. Experimental Procedure

The experimental procedures, the papers described, generally consisted of the same three parts, which are shown in Fig. 6. The preexperiment, consists of the selection of stimuli, if applicable the definition of AOI, and the selection of participants, apparatus, etc. The experimental phase includes a prequestionnaire that gathers demographic information, including age and experience in those papers that reported those factors. It also includes instructing participants in the task they were to perform and giving them 5–20 min becoming familiar with the equipment, including the eye tracker and, where applicable, the simulator. The experiment then commenced, typically separated into several short period scenarios or tasks. Some studies included as part of the experimental phase a postquestionnaire or debriefing for participant feedback on issues like difficulty ranking and self-evaluation, etc. The postexperiment consists primarily of data analysis.

D. Frequency of Use on Types of Graphics

All the surveyed papers used visualization in their works. The frequency of use of each type of graphic is defined as the number of times it appears across the papers divided by the total number of the surveyed papers. Fig. 7 shows these numbers for the automobile-related papers and the aviation-related papers.

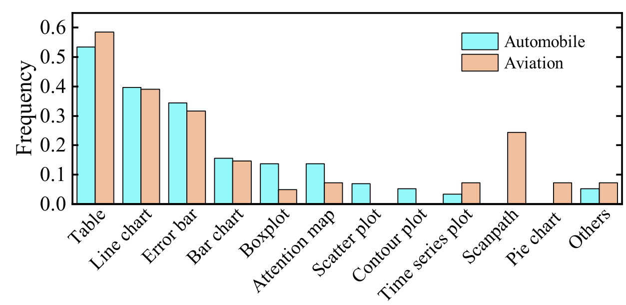

Fig. 7. Frequency of use on visualization in the surveyed automobile and aviation related papers.

TABLE IV
RECOMMENDED VISUALIZATION BASED ON THE DATA EMPHASIS

Visualization	Data emphasis
Table	Maximization of the presented data
Bar chart	Eye movement percentage on specific AOIs
Boxplot and error bar	Eye movement percentage on specific AOIs and its variance
Heat map	Eye movement density in spatial order
Time series plot	Eye movement in temporal order
Scanpath	Eye movement in both temporal and spatial order

Tables appeared in the greatest number of papers and then, in descending order, the line chart, the error bar.

There are many similarities in the selection of graphical representations of data in the two sets of papers. Tables are particularly common because they provide a visual grouping of information; line charts show data variables and trends very clearly and are easy to read and plot. The prevalence of the error bar, bar graph, and boxplot, all of which intuitively depict the differences between each parameter and the variance of the differences reflect the importance of mean value, which is essential in eye-tracking studies.

The main difference between the two sets of papers with respect to graphical representation of data are that attention maps are more favored in the automobile studies and scanpaths are favored in the aviation studies. This may reflect relative emphasis on fixation density distribution and the spatial distribution of fixation and saccade of drivers and pilots, respectively. The recommended graphical representation for particular focus is summarized in Table IV.

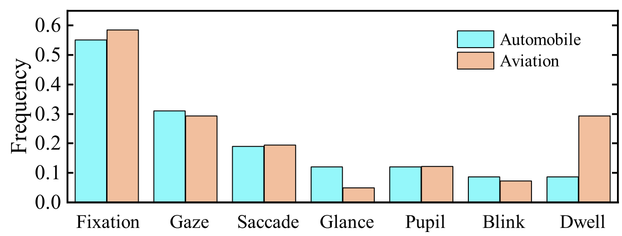

Fig. 8. Frequency of use on eye-metric data in the surveyed automobile and aviation related papers.

TABLE V
RECOMMENDED EYE METRIC DATA BASED ON RESEARCH THEME

Research theme	Recommended eye metric data
Performance	Fixation related data
Fatigue	Blink subordinated with saccadic and pupil related data
Mental workload	1. Pupil related data 2. Fixation related data 3. Combination of various eye metric data
Hazard detection	Fixation and dwell time related data
Experience and expertise	Fixation related data

TABLE VI
RECOMMENDED CONDITION OF USE FOR THE AOI DEFINITION METHODS

AOI definition method	Condition of use
Expert defined	1. High fixation density areas cannot be predicted before eye movement data is acquired [44] [64]. 2. There are similar studies to refer to for appropriate and quick AOI definition [82] [83]. 3. There is no clear way to separate the stimuli. Possible applications: marine crane lifting, mooring system replacement, ship maneuvering, wind turbine installation, etc.
Stimulus-generated	1. Fixated areas are clear before the experiment is conducted [3] [38] [48]. 2. How to separate the stimuli is clear [54] [63] [112]. Possible applications: towing, dynamic positioning (DP), navigation, operation of underwater robots, etc.
Attention map	1. High dense fixation areas are difficult to determine before eye movement data is analyzed [40] [62] [72]. 2. It can only be used to define the AOIs after the experiment.
Clustering algorithm	1. High dense fixation areas are difficult to decide before eye movement data is analyzed [75]. 2. It can only be used to define the AOIs after the experiment.

E. Frequency of Use on Eye Metric Data

The frequency of use of each type of eye-metric data is defined as the number of uses of each type across the papers, divided by the total number of papers on each industry. All the surveyed papers used eye metric data in their works. As the fundamental element of the eye-movement data, gaze data should be recorded before fixation becomes clustered. Therefore, gaze is counted only when it is emphasized and documented in the surveyed papers.

Fig. 8 indicates the frequency of use of each type of eye-metric data in the surveyed papers. Most types of data appeared with similar frequency in the two sets of papers, and fixation and gaze are the most common in both sets. However, glance and dwell, are an exception, as glance is more common in automobile-related papers and dwell is more common in aviation-related papers. Specific eye-metric data recommended based on the research theme are shown in Table V.

V. FUTURE EYE TRACKING STUDIES FOR MARINE OPERATIONS

Eye-tracking studies of marine operations have several similarities with the reviewed studies in automobile and aviation.

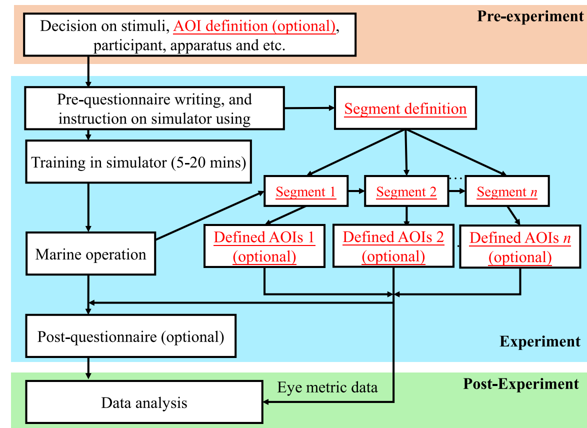

Fig. 9. Proposed experimental procedure for the marine operation.

First, the experiment is usually conducted in a simulator. Second, research topics and experimental design and methods such as sampling are also similar across these fields. This makes it easier to transfer knowledge from automobile- and aviation-based studies to marine operation studies. The sections below describe how the knowledge assembled above about methodology and experimental design can be transferred to eye tracking of marine operators, addressing the AOI definition method, and experimental design and procedure. A case study on marine operation follows, that describes the impact of such knowledge transfer.

First, the experiment is usually conducted in a simulator. Then, research topic, experimental design, and procedure such as study participant are also similar across these fields. This makes it easier to transfer the knowledge gathered here about automobile- and aviation-based studies to marine operation studies. The sections below describe how the knowledge assembled above about methodology and experimental design can be transferred to eye tracking of marine operators, addressing the AOI definition method and experimental design, and procedure. A case study on marine operation follows, that describes the impact of such knowledge transfer.

A. Methodology Transfer

As discussed in Section III, AOI definition methods can be tailored to experimental conditions and research theme. AOI definition for marine operations is similar to AOI definition for automobile and aviation in many respects. All three have similar working scenarios and similar AOIs such as outside the window and control panel. However, marine operations have some key differences in AOI from the other two. First, an operation may consist of several segments that operators must perform in a particular sequence. Second, in each segment, the focus is different, and thus the defined AOIs usually are different. For example, in a crane-lifting application, the defined AOIs can be crane-tip, payload when the payload is above the sea, and switched to monitors when the payload is submerged. This suggests an eye-tracking study in marine operation would have to have different AOIs for each segment.

Table VI shows the recommended conditions of use for AOI definition methods. Our review suggests that expert-defined and stimulus-generated AOIs are the most common, and are probably

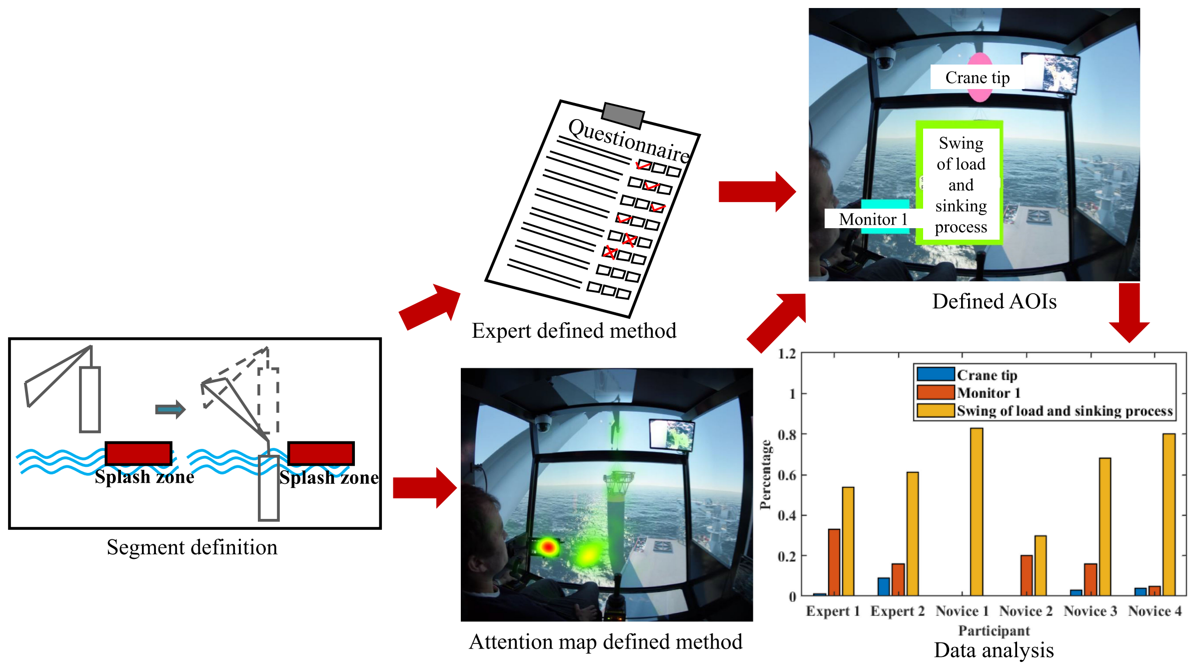

Fig. 10. Flow chart of how the AOIs were defined and the experimental procedure used in the case study.

suited eye-tracking studies in marine operations. It also suggests that the attention map method and clustering algorithm method are good alternates to allow AOI definition through data analysis. More specifically, for stimuli that have unpredictable high fixation areas such as marine crane lifting [25], mooring system replacement, ship maneuvering, and wind turbine installation, the expert-defined method is the most appropriate. When the stimuli are easy to separate, or the high fixation areas are easy to estimate such as towing, dynamic positioning [118], navigation [26], [27], and operation of underwater robots such as a remotely operated vehicle, the stimulus-generated defined method is the more suitable approach. In addition, the attention-map defined method and algorithm-defined method can be used to define the AOI according to the emphasis of the AOIs.

B. Experiment Transfer

The characteristics of the experiments surveyed are stimuli selection, research theme selection, experimental procedure design, participant selection, visualization method selection, and eye-metric data selection. Based on the analysis in Section IV, we posit that AOI-based stimuli should be used more in marine operation than point-based stimuli because, as with aviation studies, the fixation areas are more likely to be specific areas such as instrument panels and the transition between these areas. It may make sense to emulate past studies with respect to number of participants (25–27) and participant age (around 32 years) in order to control for these factors while comparing insights from marine operations studies and automobile and aviation operations studies.

Fig. 9 depicts the proposed experimental procedure for the marine operation based on the knowledge transfer. Red underlining indicates the areas that differ from the experimental procedure for the surveyed papers described in Fig. 6. Given the fact that marine operations typically involve multiple segments that must occur in a particular sequence, and the defined AOIs for each segment are distinct, it is necessary to define and distinguish several critical segments. For visualization method selection, based on the result and discussion in Section IV, in marine operation, the selection of eye-metric data can refer to the concluded rules in Table IV. For eye metric data selection, in marine operation, a similar method of eye-metric data selection can be applied based on concluded eye-metric data selection in Table V.

C. Case Study

A case study on marine operation using the recommendations above is introduced to explore their impact in the marine operation industry. Mao *et al.* [28] experimented with crane lifting on a marine platform in a simulator to study the similarities and dissimilarities of eye behaviour between expert and novice operators. This study aligned with the recommendations above with respect to both the AOI definition and the experimental design and procedure.

For AOI definition, the whole crane lifting operation was divided into several stages and AOI was defined for each stage. Fig. 10 shows how the AOIs were defined in the case study. For one segment in a crane lifting operation, the AOIs were defined based on a combination of expert opinion and an attention map. The former was obtained through a questionnaire the participants completed, and the attention map was established by the experts after the study area was determined. Then the defined AOIs were validated through the feedback of the expert participants and the analyzed data.

The experimental design and procedure followed the proposed experimental procedure shown in Fig. 9. The segment definition was based on the prequestionnaire completed by the participants, with special attention to the expert participants. For other contents discussed in Section IV, the research theme for the case study contains the expertise and experience issue, following Table V, eye-metric data related to fixation related was used and analyzed. Because the research focus is on the transition and the relation of the defined AOIs, AOI-based stimuli were used. At the same time, guided by Table VI, because the emphasis of the data are the eye-movement percentage on specific AOIs, we selected eye-movement density in spatial order and eye movement in both temporal and spatial order, visualization of bar chart, heat map, and scanpath, respectively. The results in [28] showed comprehensive analysis of eye tracking in crane lifting operations was successful, which demonstrates the effectiveness of the experimental procedure depicted in Fig. 9.

VI. Conclusion

In this work, the recently published papers using eye tracking in automobile and aviation were surveyed and categorized to evaluate the application of this method in these two areas. The objective was to seek potential knowledge transfer to marine operations for better studying of human error. The surveyed papers were categorized according to the defined characteristics and were evaluated based on AOI definition method, experiment design, and procedure. The result suggests that expert-defined and stimulus-generated AOI definition methods are favored over other methods. The analysis also extracted aspects of experiment design and procedure. The implications for eye tracking in marine operations were extracted based on the evaluation of the surveyed papers in automobile and aviation. The instruction as to how to apply an AOI definition method for specific scenarios in marine operation was proposed; at the same time, in experimental design and procedure offered a guideline on AOI-based and point-based stimuli selection, experimental procedure design, participant selection, visualization method selection, and eye metric data selection.

References

[1] O. Palinko, A. L. Kun, A. Shyrokov, and P. Heeman, "Estimating cognitive load using remote eye tracking in a driving simulator," in *Proc. Symp. Eye-Tracking Res. Appl.*, 2010, pp. 141–144.

[2] T. Falkmer *et al.* "Investigating the spatial pattern of older drivers eye fixation behaviour and associations with their visual capacity," *J. Eye Movement Res.*, vol. 9, no. 6, pp. 1–16, 2016.

[3] F. Dehais, J. Behrend, V. Peysakhovich, M. Causse, and C. D. Wickens, "Pilot flying and pilot monitoring's aircraft state awareness during go-around execution in aviation: A behavioral and eye tracking study," *Int. J. Aerosp. Psychol.*, vol. 27, no. 1/2, pp. 15–28, 2017.

[4] M. Babu, D. JeevithaShree, G. Prabhakar, K. Saluja, A. Pashilkar, and P. Biswas, "Estimating pilots' cognitive load from ocular parameters through simulation and in-flight studies," *J. Eye Movement Res.*, vol. 12, no. 3, pp. 1–16, 2019.

[5] J. H. Goldberg, M. J. Stimson, M. Lewenstein, N. Scott, and A. M. Wichansky, "Eye tracking in web search tasks: Design implications," in *Proc. Symp. Eye Tracking Res. Appl.*, 2002, pp. 51–58.

[6] S. Sharmin, O. ŠPakov, and K.-J. Räihä, "The effect of different text presentation formats on eye movement metrics in reading," *J. Eye Movement Res.*, vol. 5, no. 3, pp. 1–9, 2012.

[7] R. C. Miall and J. Tchalenko, "A painter's eye movements: A study of eye and hand movement during portrait drawing," *Leonardo*, vol. 34, no. 1, pp. 35–40, 2001.

[8] A. S. Chetwood *et al.*, "Collaborative eye tracking: A potential training tool in laparoscopic surgery," *Surg. Endoscopy*, vol. 26, no. 7, pp. 2003–2009, 2012.

[9] V. G. Moshnyaga, "The use of eye tracking for PC energy management," in *Proc. Symp. Eye Tracking Res. Appl.*, 2010, pp. 113–116.

[10] J. Tichon and R. Burgess-Limerick, "A review of virtual reality as a medium for safety related training in mining," *J. Health Saf. Res. Pract.*, vol. 3, no. 1, pp. 33–40, 2011.

[11] S. Salehi, R. Kiran, J. Jeon, Z. Kang, E. Cokely, and V. Ybarra, "Developing a cross-disciplinary, scenario-based training approach integrated with eye tracking data collection to enhance situational awareness in offshore oil and gas operations," *J. Loss Prevention Process Industries*, vol. 56, pp. 78–94, 2018.

[12] A. Binder, B. Naderer, and J. Matthes, "A "forbidden fruit effect": A eye-tracking study on children's visual attention to food marketing," *Int. J. Environ. Res. Public Health*, vol. 17, no. 6, 2020, Art. no. 1859.

[13] P. J. Hills, C. Thompson, and J. M. Pake, "Detrimental effects of carryover of eye movement behaviour on hazard perception accuracy: Effects of driver experience, difficulty of task, and hazardousness of road," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 58, pp. 906–916, 2018.

[14] T. Itkonen, J. Pekkanen, and O. Lappi, "Driver gaze behavior is different in normal curve driving and when looking at the tangent point," *PLoS One*, vol. 10, no. 8, 2015, Art. no. e0139410.

[15] A. Feldhütter, C. Gold, S. Schneider, and K. Bengler, "How the duration of automated driving influences take-over performance and gaze behavior," in *Advances in Ergonomic Design of Systems, Products and Processes*. Berlin, Germany: Springer, 2017, pp. 309–318.

[16] C. Cengiz *et al.*, "Combined eye-tracking and luminance measurements while driving on a rural road: Towards determining mesopic adaptation luminance," *Lighting Res. Technol.*, vol. 46, no. 6, pp. 676–694, 2014.

[17] W. Liu, C. K. Liu, D. M. Zhuang, Z. Q. Liu, and X. G. Yuan, "Comparison of expert and novice eye movement behaviors during landing flight," *Adv. Mater. Res.*, vol. 383, pp. 2556–2560, 2012.

[18] F. Dehais, V. Peysakhovich, S. Scannella, J. Fongue, and T. Gateau, "Automation surprise' in aviation: Real-time solutions," in *Proc. 33rd Annu. ACM Conf. Hum. Factors Comput. Syst.*, 2015, pp. 2525–2534.

[19] R. Alonso, M. Causse, F. Vachon, R. Parise, F. Dehais, and P. Terrier, "Evaluation of head-free eye tracking as an input device for air traffic control," *Ergonomics*, vol. 56, no. 2, pp. 246–255, 2013.

[20] C. D. Cabrall, R. Happee, and J. C. de Winter, "Prediction of effort and eye movement measures from driving scene components," *Transp. Res. Part F: Traffic Psychol. Behav.*, vol. 68, pp. 187–197, 2020.

[21] A. Stankovic, M. R. Aitken, and L. Clark, "An eye-tracking study of information sampling and decision-making under stress: Implications for alarms in aviation emergencies," *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 58, no. 1, 2014, pp. 125–129.

[22] N. Merat and A. H. Jamson, "The effect of three low-cost engineering treatments on driver fatigue: A driving simulator study," *Accident Anal. Prevention*, vol. 50, pp. 8–15, 2013.

[23] X. Wu, X. Wanyan, and D. Zhuang, "Pilot's visual attention allocation modeling under fatigue," *Technol. Health Care*, vol. 23, no. Suppl. 2, pp. S373–S381, 2015.

[24] N. Moray and J. W. Senders, *Human Error: Cause, Prediction, and Reduction: Analysis and Synthesis*. Hillsdale, NJ, USA: Lawrence Erlbaum, 1991.

[25] G. Li, R. Mao, H. P. Hildre, and H. Zhang, "Visual attention assessment for expert-in-the-loop training in a maritime operation simulator," *IEEE Trans. Ind. Informat.*, vol. 16, no. 1, pp. 522–531, Jan. 2020.

[26] F. Di Nocera, S. Mastrangelo, S. P. Colonna, A. Steinhage, M. Baldauf, and A. Kataria, "Mental workload assessment using eye-tracking glasses in a simulated maritime scenario," in *Proceedings of the Human Factors and Ergonomics Society Europe*, Santa Monica, CA, USA: Human Factors Ergonom. Soc., 2016, pp. 235–248.

[27] O. S. Hareide and R. Ostnes, "Maritime usability study by analysing eye tracking data," *J. Navigation*, vol. 70, no. 5, pp. 927–943, 2017.

[28] R. Mao, G. Li, H. P. Hildre, and H. Zhang, "Analysis and evaluation of eye behavior for marine operation training–A pilot study," *J. Eye Movement Res.*, vol. 12, no. 3, pp. 1–14, 2019.

[29] T. Blascheck, K. Kurzhals, M. Raschke, M. Burch, D. Weiskopf, and T. Ertl, "State-of-the-art of visualization for eye tracking data," in *Proc. Eurographics Conf. Visualization*, 2014, pp. 63–82.

[30] K. Holmqvist, M. Nyström, R. Andersson, R. Dewhurst, H. Jarodzka, and J. Van de Weijer, *Eye Tracking: A Comprehensive Guide to Methods and Measures*. London, U.K.: OUP Oxford, 2011.

[31] K. K. E. Ellis, "Eye tracking metrics for workload estimation in flight Dec. operations," M.S. thesis, Univ. Iowa, Iowa City, IA, USA, 2009, Art. no. 288.

[32] S. Lemonnier, R. Brémond, and T. Baccino, "Gaze behavior when approaching an intersection: Dwell time distribution and comparison with a quantitative prediction," *Transp. Res. Part F: Traffic Psychol. Behav.*, vol. 35, pp. 60–74, 2015.

[33] T. Blascheck, K. Kurzhals, M. Raschke, M. Burch, D. Weiskopf, and T. Ertl, "Visualization of eye tracking data: A taxonomy and survey," *Comput. Graph. Forum*, vol. 36, no. 8, 2017, pp. 260–284.

[34] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *Ann. Internal Med.*, vol. 151, no. 4, pp. 264–269, 2009.

[35] T. G. Monteiro, C. Skourup, and H. Zhang, "Using EEG for mental fatigue assessment: A comprehensive look into the current state of the art," *IEEE Trans. Human-Mach. Syst.*, vol. 49, no. 6, pp. 599–610, Dec. 2019.

[36] G. Andrienko, N. Andrienko, M. Burch, and D. Weiskopf, "Visual analytics methodology for eye movement studies," *IEEE Trans. Visualization Comput. Graph.*, vol. 18, no. 12, pp. 2889–2898, Dec. 2012.

[37] A. J. Filtness and V. Beanland, "Sleep loss and change detection in driving scenes," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 57, pp. 10–22, 2018.

[38] S. Winkler, J. Kazazi, and M. Vollrath, "Distractive or supportive-how warnings in the head-up display affect drivers' gaze and driving behavior," in *Proc. IEEE 18th Int. Conf. Intell. Transp. Syst*., 2015, pp. 1035–1040.

[39] C. Lounis, V. Peysakhovich, and M. Causse, "Flight eye tracking assistant (FETA): Proof of concept," in *Proc. Int. Conf. Appl. Human Factors Ergonom*., 2019, pp. 739–751.

[40] B. Dolega, P. Gomolka, Z. Gomolka, and D. Kordos, "Cognitive research on pilot's eye attention during flight simulator tests," in *Proc. 5th CEAS Conf. Guid., Navigation Control*, 2019, pp. 1–14.

[41] S. He, B. Liang, G. Pan, F. Wang, and L. Cui, "Influence of dynamic highway tunnel lighting environment on driving safety based on eye movement parameters of the driver," *Tunnelling Underground Space Technol.*, vol. 67, pp. 52–60, 2017.

[42] D. Topolvśek, I. Areh, and T. Cvahte, "Examination of driver detection of roadside traffic signs and advertisements using eye tracking," *Transp. Res. Part F: Traffic Psychol. Behav.*, vol. 43, pp. 212–224, 2016.

[43] R. Zheng, K. Nakano, H. Ishiko, K. Hagita, M. Kihira, and T. Yokozeki, "Eye-gaze tracking analysis of driver behavior while interacting with navigation systems in an urban area," *IEEE Trans. Human-Machine Syst.*, vol. 46, no. 4, pp. 546–556, Aug. 2016.

[44] J. Navarro, F. Osiurak, M. Ovigue, L. Charrier, and E. Reynaud, "Highly automated driving impact on drivers' gaze behaviors during a car-following task," *Int. J. Human-Comput. Interaction*, vol. 35, no. 11, pp. 1008–1017, 2019.

[45] D. Rudi, P. Kiefer, and M. Raubal, "The instructor assistant system (iASSYST)-utilizing eye tracking for commercial aviation training purposes," *Ergonomics*, vol. 63, no. 1, pp. 61–79, 2020.

[46] M. Carroll, G. Surpris, G. Sidor, and W. Bennett Jr., "Evaluation of an eye tracking-based assessment and debrief tool for training next generation multirole tactical aviation skills," in *Proc. 18th Int. Symp. Aviation Psychol.*, 2015, pp. 536–541.

[47] E. T. Dill and S. D. Young, "Analysis of eye-tracking data with regards to the complexity of flight Dec. information automation and management-inattentional blindness, system state awareness, and EFB usage," in *Proc. 15th AIAA Aviation Technol., Integration, Operations Conf.*, 2015, pp. 2901–2916.

[48] S. Naeeri, S. Mandal, and Z. Kang, "Analyzing pilots' fatigue for prolonged flight missions: Multimodal analysis approach using vigilance test and eye tracking," *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 63, no. 1, pp. 111–115,2019.

[49] S. Hergeth, L. Lorenz, R. Vilimek, and J. F. Krems, "Keep your scanners peeled: Gaze behavior as a measure of automation trust during highly automated driving," *Human Factors*, vol. 58, no. 3, pp. 509–519, 2016.

[50] M. N. Russi-Vigoya and P. Patterson, "Analysis of pilot eye behavior during glass cockpit simulations," *Procedia Manuf.*, vol. 3, pp. 5028–5035, 2015.

[51] E. Lehtonen, O. Lappi, H. Kotkanen, and H. Summala, "Look-ahead fixations in curve driving,"*Ergonomics*, vol. 56, no. 1, pp. 34–44, 2013.

[52] F. I. Kandil, A. Rotter, and M. Lappe, "Car drivers attend to different gaze targets when negotiating closed vs. open bends," *J. Vis.*, vol. 10, no. 4, pp. 24.1–24.11, 2010.

[53] R. Eyraud, E. Zibetti, and T. Baccino, "Allocation of visual attention while driving with simulated augmented reality," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 32, pp. 46–55, 2015.

[54] J. Edquist, T. Horberry, S. Hosking, and I. Johnston, "Effects of advertising billboards during simulated driving," *Appl. Ergonom.*, vol. 42, no. 4, pp. 619–626, 2011.

[55] P. Konstantopoulos, P. Chapman, and D. Crundall, "Driver's visual attention as a function of driving experience and visibility. using a driving simulator to explore drivers' eye movements in day, night and rain driving," *Accident Anal. Prevention*, vol. 42, no. 3, pp. 827–834, 2010.

[56] K. Moore and L. Gugerty, "Development of a novel measure of situation awareness: The case for eye movement analysis," in *Proc. Human Factors Ergonom. Soc. Annu. Meet.*, vol. 54, no. 19, pp. 1650–1654, 2010.

[57] E. Dubois, C. Blättler, C. Camachon, and C. Hurter, "Eye movements data processing for ab initio military pilot training," in *Proc. Int. Conf. Intell. Decis. Technol*., 2017, pp. 125–135.

[58] M. Friedrich, N. Rubẃinkel, and C. Möhlenbrink, "A guideline for integrating dynamic areas of interests in existing set-up for capturing eye movement: Looking at moving aircraft," *Behavior Res. Methods*, vol. 49, no. 3, pp. 822–834, 2017.

[59] Z. Kang, S. Mandal, J. Crutchfield, A. Millan, and S. N. McClung, "Designs and algorithms to map eye tracking data with dynamic multielement moving objects," *Comput. Intell. Neurosci.*, vol. 2016, 2016, Art. no. 9354760.

[60] J. M. Covelli, J. P. Rolland, M. Proctor, J. P. Kincaid, and P. Hancock, "Field of view effects on pilot performance in flight," *Int. J. Aviation Psychol.*, vol. 20, no. 2, pp. 197–219, 2010.

[61] C. Lehsing *et al.*, "Effects of simulated mild vision loss on gaze, driving and interaction behaviors in pedestrian crossing situations," *Accident Anal. Prevention*, vol. 125, pp. 138–151, 2019.

[62] A. Löcken, F. Yan, W. Heuten, and S. Boll, "Investigating driver gaze behavior during lane changes using two visual cues: Ambient light and focal icons," *J. Multimodal User Interfaces*, vol. 13, no. 2, pp. 119–136, 2019.

[63] W. Chen, X. Zhuang, Z. Cui, and G. Ma, "Drivers recognition of pedestrian road-crossing intentions: Performance and process," *Trans. Res. Part F: Traffic Psychol. Behaviour*, vol. 64, pp. 552–564, 2019.

[64] R. Paeglis, K. Bluss, and A. Atvars, "Driving experience and special skills reflected in eye movements," in *Proc. SPIE*, vol. 8155, 2011, Art. no. 815516.

[65] M. Hashash, M. A. Zeid, and N. M. Moacdieh, "Social media browsing while driving: Effects on driver performance and attention allocation," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 63, pp. 67–82, 2019.

[66] L. Ábele, S. Haustein, L. M. Martinussen, and M. Møller, "Improving drivers' hazard perception in pedestrian-related situations based on a short simulator-based intervention," *Transp. Res. Part F: Traffic Psychol. Behav.*, vol. 62, pp. 1–10, 2019.

[67] M. S. Jessee, "Ocular activity as a measure of mental and visual workload," *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 54, no. 18, pp. 1350–1354, 2010.

[68] N. Weibel, A. Fouse, C. Emmenegger, S. Kimmich, and E. Hutchins, "Let's look at the cockpit: Exploring mobile eye-tracking for observational research on the flight deck," in *Proc. Symp. Eye Tracking Res. Appl.*, 2012, pp. 107–114.

[69] N. M. Moacdieh, J. C. Prinet, and N. B. Sarter, "Effects of modern primary flight display clutter: Evidence from performance and eye tracking data," *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 57, no. 1, pp. 11–15, 2013.

[70] K. Latorella *et al.*, "Dual oculometer system for aviation crew assessment," in *Proc. 54th Annu. Meeting Human Factors Ergonom. Soc.*, 2010, pp. 1–6.

[71] S. A. Najar and P. K. Sanjram, "Gaze behavior and human error in distracted driving: Unlocking the complexity of articulatory rehearsal mechanism," *Transp. Res. Part F: Traffic Psychol. Behav.*, vol. 59, pp. 12–23, 2018.

[72] J. Winter, S. Fotios, and S. Völker, "Gaze direction when driving after dark on main and residential roads: Where is the dominant location?," *Lighting Res. Technol.*, vol. 49, no. 5, pp. 574–585, 2017.

[73] Q. C. Sun, J. C. Xia, J. He, J. Foster, T. Falkmer, and H. Lee, "Towards unpacking older drivers' visual-motor coordination: A gaze-based integrated driving assessment," *Accident Anal. Prevention*, vol. 113, pp. 85–96, 2018.

[74] P. Konstantopoulos, P. Chapman, and D. Crundall, "Exploring the ability to identify visual search differences when observing drivers' eye movements," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 15, no. 3, pp. 378–386, 2012.

[75] Q. Xu, T.-y. Guo, F. Shao, and X.-j. Jiang, "Division of area of fixation interest for real vehicle driving tests," *Math. Problems Eng.*, vol. 2017, 2017, Art. no. 3674374.

[76] J. H. Yang, Q. Kennedy, J. Sullivan, and R. D. Fricker, "Pilot performance: Assessing how scan patterns & navigational assessments vary by flight expertise," *Aviation, Space, Environ. Med.*, vol. 84, no. 2, pp. 116–124, 2013.

[77] C. Bruder, H. Eißfeldt, P. Maschke, and C. Hasse, "Differences in monitoring between experts and novices," *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 57, no. 1, pp. 295–298, 2013.

[78] M. Robinski and M. Stein, "Tracking visual scanning techniques in training simulation for helicopter landing," *J. Eye Movement Res.*, vol. 6, no. 2, pp. 1–17, 2013.

[79] C. Desmet and K. Diependaele, "An eye-tracking study on the road examining the effects of handsfree phoning on visual attention," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 60, pp. 549–559, 2019.

[80] Y. Yang, J. Chen, S. M. Easa, X. Zheng, W. Lin, and Y. Peng, "Driving simulator study of the comparative effectiveness of monolingual and bilingual guide signs on chinese highways," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 68, pp. 67–78, 2020.

[81] A. Haslbeck and K. Bengler, "Pilots' gaze strategies and manual control performance using occlusion as a measurement technique during a simulated manual flight task," *Cogn.*, *Technol. Work*, vol. 18, no. 3, pp. 529–540, 2016.

[82] M. Reynal, Y. Colineaux, A. Vernay, and F. Dehais, "Pilot flying vs. pilot monitoring during the approach phase: An eye-tracking study," in *Proc. Int. Conf. Human-Comput. Interaction Aerosp.*, 2016, pp. 1–7.

[83] E. T. Dill, S. D. Young, T. S. Daniels, and E. T. Evans, "Analysis of eye-tracking data during conditions conducive to loss of airplane state awareness," in *Proc. 17th AIAA Aviation Technol., Integration, Operations Conf.*, 2017, pp. 3277–3288.

[84] T. Deng, K. Yang, Y. Li, and H. Yan, "Where does the driver look? Top-down-based saliency detection in a traffic driving environment," *IEEE Trans. Intell. Transp. Syst.*, vol. 17, no. 7, pp. 2051–2062, Jul. 2016.

[85] X. He, L. Wang, X. Gao, and Y. Chen, "The eye activity measurement of mental workload based on basic flight task," in *Proc. IEEE 10th Int. Conf. Ind. Inform.*, 2012, pp. 502–507.

[86] A. Tamura, Y. Wada, N. Shimizu, T. Inui, and A. Shiotani, "Correlation of climbing perception and eye movements during daytime and nighttime takeoffs using a flight simulator," *Acta Oto-Laryngologica*, vol. 136, no. 5, pp. 433–438, 2016.

[87] G. K. Kountouriotis, R. M. Wilkie, P. H. Gardner, and N. Merat, "Looking and thinking when driving: The impact of gaze and cognitive load on steering," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 34, pp. 108–121, 2015.

[88] S. W. Savage, D. D. Potter, and B. W. Tatler, "Does preoccupation impair hazard perception? A simultaneous eeg and eye tracking study," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 17, pp. 52–62, 2013.

[89] V. Faure, R. Lobjois, and N. Benguigui, "The effects of driving environment complexity and dual tasking on drivers' mental workload and eye blink behavior," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 40, pp. 78–90, 2016.

[90] A. S. Le, T. Suzuki, and H. Aoki, "Evaluating driver cognitive distraction by eye tracking: From simulator to driving," *Transp. Res. Interdisciplinary Perspectives*, 2019, Art. no. 100087.

[91] J. Rajesh and P. Biswas, "Eye-gaze tracker as input modality for military aviation environment," in *Proc. IEEE Int. Conf. Intell. Comput., Instrum. Control Technol.*, 2017, pp. 558–564.

[92] C. P. Ryffel, C. M. Muehlethaler, S. M. Huber, and A. Elfering, "Eye tracking as a debriefing tool in upset prevention and recovery training (UPRT) for general aviation pilots," *Ergonomics*, vol. 62, no. 2, pp. 319–329, 2019.

[93] Z. Kang and S. J. Landry, "Using scanpaths as a learning method for a conflict detection task of multiple target tracking," *Human Factors*, vol. 56, no. 6, pp. 1150–1162, 2014.

[94] M. Itkonen, S. Shimoda, and T. Kumada, "Quantifying the difference between intention and outcome in driving performance," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 62, pp. 126–134, 2019.

[95] Y. Yamani, P. B1cks1z, J. Unverricht, and S. Samuel, "Impact of information bandwidth of in-vehicle technologies on drivers' attention maintenance performance: A driving simulator study," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 59, pp. 195–202, 2018.

[96] L. Yekhshatyan and J. D. Lee, "Changes in the correlation between eye and steering movements indicate driver distraction," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 136–145, Mar. 2013.

[97] S. Benedetto, M. Pedrotti, L. Minin, T. Baccino, A. Re, and R. Montanari, "Driver workload and eye blink duration," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 14, no. 3, pp. 199–208, 2011.

[98] D. P. Crabb *et al.*, "Exploring eye movements in patients with glaucoma when viewing a driving scene," *PLoS One*, vol. 5, no. 3, 2010, Art. no. e9710.

[99] T. Zimasa, S. Jamson, and B. Henson, "Are happy drivers safer drivers? Evidence from hazard response times and eye tracking data," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 46, pp. 14–23, 2017.

[100] D. P. Upahita, Y. D. Wong, and K. M. Lum, "Effect of driving experience and driving inactivity on young driver's hazard mitigation skills," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 59, pp. 286–297, 2018.

[101] T. Zhang, A. H. Chan, Y. Ba, and W. Zhang, "Situational driving anger, driving performance and allocation of visual attention," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 42, pp. 376–388, 2016.

[102] L. L. Di Stasi *et al.*, "Effects of long and short simulated flights on the saccadic eye movement velocity of aviators," *Physiol. Behavior*, vol. 153, pp. 91–96, 2016.

[103] C. Diaz-Piedra, H. Rieiro, A. Cherino, L. J. Fuentes, A. Catena, and L. L. Di Stasi, "The effects of flight complexity on gaze entropy: An experimental study with fighter pilots," *Appl. Ergonom.*, vol. 77, pp. 92–99, 2019.

[104] T. C. Köbler *et al.*, "Driving with glaucoma: Task performance and gaze movements," *Optometry Vis. Sci.*, vol. 92, no. 11, pp. 1037–1046, 2015.

[105] A. Lotz, N. Russwinkel, and E. Wohlfarth, "Response times and gaze behavior of truck drivers in time critical conditional automated driving take-overs," *Transp. Res. Part F: Traffic Psychol. Behaviour*, vol. 64, pp. 532–551, 2019.

[106] T. Louw and N. Merat, "Are you in the loop? Using gaze dispersion to understand driver visual attention during vehicle automation," *Transp. Res. Part C: Emerg. Technol.*, vol. 76, pp. 35–50, 2017.

[107] Y. Liao, S. E. Li, W. Wang, Y. Wang, G. Li, and B. Cheng, "Detection of driver cognitive distraction: A comparison study of stop-controlled intersection and speed-limited highway," *IEEE Trans. Intell. Transp. Syst.*, vol. 17, no. 6, pp. 1628–1637, Jun. 2016.

[108] K. Naqshbandi, T. Gedeon, and U. A. Abdulla, "Automatic clustering of eye gaze data for machine learning," in *Proc. IEEE Int. Conf. Syst., Man, Cybern.*, 2016, pp. 001239–001244.

[109] N. B. Sarter, R. J. Mumaw, and C. D. Wickens, "Pilots' monitoring strategies and performance on automated flight decks: An empirical study combining behavioral and eye-tracking data," *Human Factors*, vol. 49, no. 3, pp. 347–357, 2007.

[110] F. Dehais, M. Causse, and J. Pastor, "Embedded eye tracker in a real aircraft: New perspectives on pilot/aircraft interaction monitoring," in *Proc. 3rd Int. Conf. Res. Air Transp.*, 2008, pp. 303–309.

[111] R. Y. Koh, T. Park, C. D. Wickens, L. T. Ong, and S. N. Chia, "Differences in attentional strategies by novice and experienced operating theatre scrub nurses," *J. Exp. Psychol.: Appl.*, vol. 17, no. 3, pp. 233–246, 2011.

[112] P. M. van Leeuwen, R. Happee, and J. C. de Winter, "Changes of driving performance and gaze behavior of novice drivers during a 30-min simulator-based training," *Procedia Manuf.*, vol. 3, pp. 3325–3332, 2015.

[113] A. K. Mackenzie and J. M. Harris, "A link between attentional function, effective eye movements, and driving ability," *J. Exp. Psychol.: Human Perception Perform.*, vol. 43, no. 2, p. 381, 2017.

[114] L. N. van der Laan, I. T. Hooge, D. T. De Ridder, M. A. Viergever, and P. A. Smeets, "Do you like what you see? The role of first fixation and total fixation duration in consumer choice," *Food Qual. Preference*, vol. 39, pp. 46–55, 2015.

[115] A. Santella and D. DeCarlo, "Robust clustering of eye movement recordings for quantification of visual interest," in *Proc. Symp. Eye Tracking Res. Appl.*, 2004, pp. 27–34.

[116] Y. Gu, C. Wang, R. Bixler, and S. D'Mello, "ETGraph: A graph-based approach for visual analytics of eye-tracking data," *Comput. Graph.*, vol. 62, pp. 1–14, 2017.

[117] J. H. Goldberg and J. C. Schryver, *Eye-Gaze Determination of User Intent at the Computer Interface,"in Studies in Visual Information Processing*. New York, NY, USA: Elsevier, 1995, vol. 6, pp. 491–502.

[118] F. B. Bjørneseth, L. Clarke, M. Dunlop, and S. Komandur, "Towards an understanding of operator focus using eye-tracking in safety-critical maritime settings," in *Proc. Int. Conf. Hum. Factors Ship Des. Operation*, 2014, pp. 1–9.